THE INFLUENCE OF BATHYMETRY, SEDIMENT THICKNESS, AND PERMEABILITY STRUCTURE ON OFF-AXIS ENERGY AND MASS FLUXES

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Long-term Scientific Objectives

The long-term objectives of this project are to understand how fluid flow taking place on seafloor ridge flanks influences the physical evolution of upper oceanic crust. This project is a first step towards the developing more comprehensive models of upper crustal evolution that include feedbacks between physical, chemical, and thermal processes. Additional direct measurements of permeability within the upper crust have confirmed that most transmissivity is concentrated within this zones, probably associated with primary crustal architecture. In this project we are examining how this crustal structure influences physical patterns of heat and fluid flow.

Project Objectives

The operational goals of this project have been:

- to design and implement a curvilinear mesh generator and associated graphics and utility programs for use with the numerical model of coupled heat and fluid flow;
- to test the new mesh configurations by simulating the area around DSDP/ODP Site 504 in the eastern Pacific Ocean;
- to conduct comprehensive parametric tests to determine the influence of physical variables (bathymetry, basement relief, permeability distribution, basal heat flow) on the extent, direction, and intensity of hydrothermal circulation;
- to compile, review, and synthesize bathymetry, sediment thickness, and heat flow data from other sites where relationships between these variables can be elucidated; and
- to complete simulations of other field areas and general settings to determine likely influences on off-axis hydrothermal activity in these settings.

During the first year of this project (FY92) we completed the first three objectives listed above. In FY93, we prepared and submitted results of this work for publication in a special issue of the Journal of Geophysical Research on Oceanic Crustal Evolution, which was published in February. We then turned attention to the next two goals: modeling addition field settings and modifying the novel mesh-generator (and associated pre- and post-processors for the model) developed for the first part of this project, to simulate settings that include basement that penetrates through the sediment layer, as with seamounts or in sediment ponds on very young crust.

FY94 Progress and Present Status

In Spring 1994 we submitted a new manuscript for publication in the Journal of Geophysical Research. The results reported in this paper are summarized in the following paragraph.

There is a strong positive correlation between bathymetric and well-navigated heat flow data from the Galapagos Mounds hydrothermal area and the east flank of the Juan de Fuca Ridge. The same correlation is apparent at Deep Sea Drilling Project/Ocean Drilling Program (DSDP/ODP) site 504, where it provides a constraint on the intensity (and to a lesser extent, geometry) of ridge-flank hydrothermal circulation. We tested the implications of this correlation with a hydrogeological model of the volcanic crust that contains significant permeability mainly within a few thin layers (tens of meters thick) in the upper few hundred meters of basement, consistent with observations in DSDP/ODP holes into upper oceanic crust. These simulations are compared directly to others in which the same bulk permeability is represented more homogeneously within the upper crust. A model with thin permeable zones and subtle relief beneath a flat seafloor can explain the variations in seafloor heat flow observed on one part of the Juan de Fuca Ridge east flank, as can a model with a flat seafloor and basement top, but relief within the most permeable zone (see figure). We explore the importance of layered heterogeneities versus explicit permeability anisotropy in these simulations through a series of parametric tests. Some form of permeability anisotropy appears to be required in order to achieve efficient lateral heat transport within the upper volcanic crust so as to produce the common seafloor heat flow-basement relief correlation. This permeability anisotropy may result directly from the primary architecture of the volcanic crust. Numerical results suggest that within an anisotropic system such as the upper oceanic crust, the length-scale of heat flow variations (and therefore the length scale of underlying hydrothermal convection cells) is not an indication of the depth extent of fluid flow. Rather, the length scale of heat flow anomalies may reflect the length scale of relief along aquifer boundaries, while the depth of vigorous flow is constrained by the depth extent of significant permeability.

In completing this work we realized that it would be necessary to rewrite completely some of the pre- and post-processors used to run the numerical model in order to simulate a realistic range of physical parameters for much of the seafloor, including the penetration of basaltic outcrops through the sediment layer. This effort has occupied much of the remainder of our time during FY94, but programming of the new mesh generator is now complete. Following debugging and completion of associated programs used to interpret model output, we will begin simulations of additional settings.

FY94 Publication supported by ONR

Fisher, A., Becker, K., and Narasimhan, T., Off-axis hydrothermal circulation: a refined model of processes at DSDP/ODP Site 504 and parametric tests, *J. Geophys. Res.*, 99: 3097-3121.

Fisher, A., and Becker, K. The correlation between heat flow and basement relief: observational and numerical examples and implications for upper crustal permeability, *J. Geophys. Res.*, submitted, reviewed, and revised.

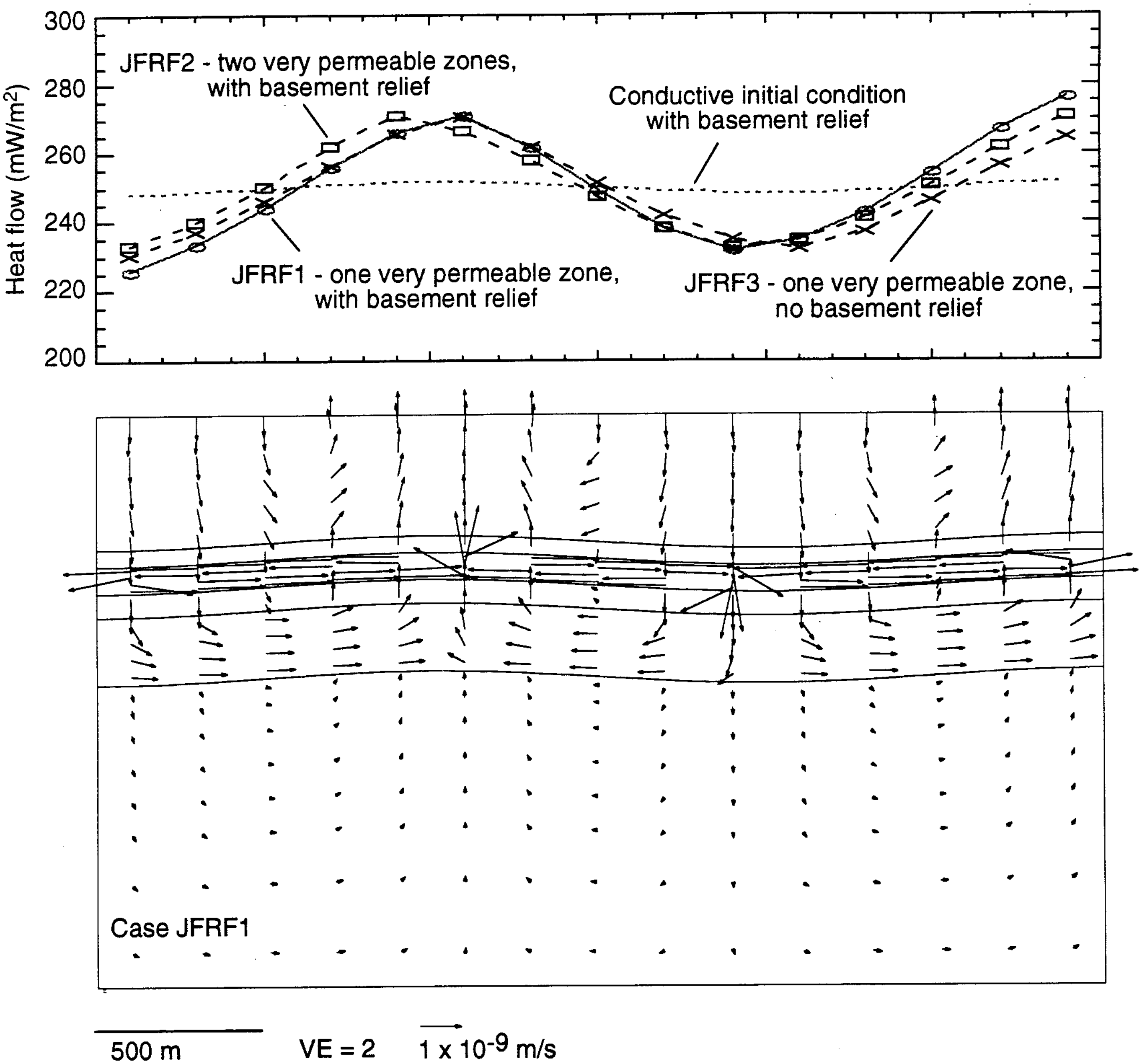
FY94 Abstracts

Fisher, A. and K. Becker, Models of crustal permeability based on the correlation between seafloor heat flow and basement relief and numerical models, submitted for annual GSA meeting.

Fisher, A., and Becker, K, Inferences on the distribution of permeability in the upper oceanic crust from observations and numerical models, *EOS* 74/43 (supplement): 242.

Larson, R., A. Fisher, R. Jarrard, and Becker, K., Highly permeable and layered Jurassic oceanic crust in the western Pacific, *EOS* 74/43 (supplement): 241.

Fisher, A., Becker, K., and Wheat, C. G., Inferences on the nature of off-axis crustal permeability, based on comparisons of numerical models with thermal and chemical observations, *Third RIDGE Theoretical Workshop.*



Seafloor heat flow (Cases JFRF1, JFRF2, and JDFR3) superimposed over fluid flow vectors from Cases JFRF1 of part of the Juan de Fuca Ridge eastern flank. Case JFRF1 includes a single 40-m zone with very high permeability, while Case JFRF2 includes two zones (comprising 40 m in total thickness) with very high permeability. Both these cases include 20-m amplitude variations in basement relief. Case JFRF3 included flat seafloor and flat basement, but 20 m of relief within the most permeable basalt. All three cases resulted in similar heat flow and fluid flow patterns. Velocities are plotted on a log scale. Note vertical exaggeration (VE). Seafloor heat flow is presented also for the conductive initial condition used for both these cases. The seafloor heat flow resulting from tests with bulk permeability of 10^{-13} m^2 for the upper 100 m of basaltic crust is identical to that for the conductive initial condition. These results suggest that thin permeable zones in basement in combination with subtle basement relief (or flat basement with relief in the permeable zones) could explain the observed pattern of seafloor heat flow in this setting.

FY94 ONR Statistics Report
One Year Report: One Per Grant

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Number of papers submitted for refereed journal, but in subscription or in press:		1
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Number of books/chapters in press:		0
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Number of patents filed:		0
Number of patents granted (list attached):		0
Number of invited presentations at conferences, workshops, etc.:		0
Number of contributed presentations at conferences, workshops, etc.:		4
Honors, Awards, Prizes for work performed under this grant (list attached):		0
Number of graduate students supported under this grant:		0
Number of post-docs supported under this grant:		0
Number of female graduate students supported under this grant:		0
Number of minority (**Black**, Aleuts, Amerindians, Hispanics, etc.) graduate students supported under this gran		0
Number of female post-docs supported under this grant:		0
Number of minority post-docs supported under this grant:		0